DOCUMENT RESUME

ED 465 448 PS 030 423

AUTHOR Chen, Shing-Jen, Ed.; Murohashi, Harumitsu, Ed.; Fujino, Yuki, Ed.
TITLE Research and Clinical Center for Child Development Annual Report, 2000-2001.
INSTITUTION Hokkaido Univ., Sapporo (Japan). Faculty of Education.
REPORT NO No-24
ISSN ISSN-0386-8435
PUB DATE 2002-03-00
NOTE 39p.; For 1999-2000 report, see ED 454 956.
AVAILABLE FROM Research and Clinical Center for Child Development, Graduate School of Education, Hokkaido University, Nishi 7, Kita 11, Kita ku, Sapporo 060-0811, Japan. Tel: 011-706-3106.
PUB TYPE Collected Works - General (020)
EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Acoustics; Age Differences; *Attention; Auditory Perception; Caregiver Role; *Caregiver Speech; *Child Development; Foreign Countries; Infant Behavior; *Infants; Mothers; *Parent Child Relationship
IDENTIFIERS *Fetal Development; Fetal Research; Gaze Patterns; Japan

ABSTRACT

This annual report presents several articles related to the work of the Clinical Center for Child Development at Hokkaido University in Sapporo, Japan. The articles are: (1) "Joint Attention as a System Property of the Infant-Caregiver Interaction System"(Tsuneda Miho and Shing-Jen Chen); (2) "Age-Related Change in Japanese Maternal Infant-Directed Speech and Infant's Vocal Response" (Katsuko Niwano and Kuniaki Sugai); and (3) "Measuring Human Fetal Responses to Sounds by Umbilical and Middle-Cerebral Artery Velocity Waveforms: A Preliminary Study" (Kiyobumi Kawakami, Kiyoko Takai-Kawakami, Naoe Masuda, Makoto Suzuki, Yukiko Shimizu, and Takumi Yanaihara). (KB)

ISSN 0386-8435

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RESEARCH AND CLINICAL CENTER FOR CHILD DEVELOPMENT

Annual Report
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RCCCD

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Annual Report
2000-2001
No.24

March 2002
Editors:
Shing-Jen Chen, Harumitsu Murohashi, Yuki Fujino

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JOINT ATTENTION AS A SYSTEM PROPERTY OF THE INFANT-CAREGIVER INTERACTION SYSTEM

Tsuneda Miho & Shing-Jen Chen
Hokkaido University

Abstract

The development of visual joint attention has been examined almost exclusively from the point of view of the infant's capacity. Researchers have focused on issues such as its developmental origins and timing, its implications for the development of social cognition, and the possible mechanisms for the changing patterns of joint attention. However, this approach does not reveal how this skill emerges from the infant's interaction with the caregiver. In this paper, joint attention is viewed as an interaction state achieved by the infant and the caregiver system. The development of this state is described first as led by the caregiver monitoring the attention of the infant and overcoming the spatial constraints. As the infant becomes able to control his posture and to respond to caregiver's attention getting bids, caregiver begins to introduce objects and their manipulations, thus extending the frame of joint attention. With the emergence of language and narratives, the 'window' of joint attention opens to include events beyond the here and now. The interaction system gradually overcomes the temporal constraints. The last stage of development sees the infant actively taking over the role of the caregiver by initiating attention getting. A full-fledge joint attention is characterized by the dyad's having overcome both the spatial and the temporal constraints.

Key Words : gaze following, joint attention, caregiver's role, spatial constraints, temporal constraints.

Introduction

At the end of the first year, an infant begins to be able to engage in an interaction involving the caregiver, an object and him(her)self. In this so-called 'triangular relationship', the infant's attention and behavior to the object have to be coordinated with the attention and behavior of the caregiver. It is considered an important step for the infant to be able to coordinate his(her) own gaze according to that of the caregiver. Although parents have long known about this, Scaife & Bruner first demonstrated the young infant's gaze following in 1975. This ability to follow the gaze of the other has been recognized as an important basic skill for many future developments, such as the development of deictic gestures (e.g., finger pointing), and acquisition of language, and theory of mind (Asao, 1992; Bakeman & Adamson, 1984; Baldwin, 1995; Bruner, 1983, Butterworth, 1995; Yamada, 1987; Muto, 1994). While in later researches, scholars have referred to gaze-following by using the term visual joint attention, later research has subsequently encouraged the demonstrations of other joint attention phenomena such as, social referencing, early protocommunicative gestures, imitation, and early productive language (Bruner, 1995:1-14).

Current Emphasis on Individual Ability

For developmentalist, one of the first natural questions to ask about joint attention is the timing of its ontogenetic appearance and its developmental sequences. Indeed, researches following Scaife & Bruner's paper asked these central questions. Butterworth, for example, conducted observations in the laboratory with infants from 6 to 18 months of age with their mothers in order to find out when young infants begin to look where the adult looks (Butterworth & Cochran, 1980). Other investigators such as Corkum & Moore, Baron-Cohen, and Tomasello continued this line of research, with little reference to the caregiver's role in the construction of joint attention (Corkum & Moore, 1995:64-65; Baron-Cohen, 1995a:43,1995b; Tomasello, 1995:124-125). One implication of this emphasis on the origins and the timing of development of individual skill is the neglect of how it emerges from dyadic interaction. Furthermore, because the appearance of gaze following, or visual joint attention behavior alone, does not guarantee the intersubjective mutual understanding of the dyad, the individual ability perspective does not help researchers asking questions which lead to understanding joint attention as a significant cultural activity.

In addition to examining the accuracy with which infants of different ages could localize the targets of another's attention, Butterworth and colleagues suggested three mechanisms, ecological mechanism, geometric mechanism, and representational mechanism, for accounting the developmental patterns of infants' joint attention behavior. According to Butterworth, while infants before 6 months are not able to look to the direction of the adult's orientation, at 6 months they look to the correct side of the room, although precise location specification was not achieved. The first stage is achieved by the change in the mother's gaze serving as an orienting signal specifying the direction for the infant to look while the interesting object completes the communicative link with the adult to specify the position at which to look (Butterworth, 1995:32). Then at 12 months, infants begin to be able to localize the target identified by the adult's gaze, even when there are more than one object along the infant's scan path. This second stage is achieved by the infants seemingly extrapolating an invisible line between the mother and the referent of her gaze, as plotted from the infant's position (Butterworth, 1995:32). At 18 months, with access of representational space, infants are able to follow the adults' gaze (Butterworth, 1995:32-33).

Corkum & Moor, on the other hand, set out to find out what cues or behaviors are important for establishing joint visual attention for young infants. Especially, they proposed to examine the developmental changes in the social cues that infants rely on for establishing joint visual attention (Corkum & Moore, 1995:64-65). Adopting conditioned head turn paradigm, they concluded that the onset of joint visual attention is around 10-12 months, considerablely later than what had been suggested earlier (Corkum & Moore, 1995:78). They also suggested that learning, in terms of contingent feedback of the adult, is a possible route of acquisition for the joint attention response (Corkum & Moore, 1995:81).

These researches, ranging from that of Scaife & Bruner to that of Corkum & Moore, have examined the origin of joint visual attention from the viewpoint of the development of individual ability, i.e., an ontogenetic viewpoint. Baron-Cohen, on the other hand, has approached it from a evolutionary psychology point of view (Baron-Cohen, 1995a:43,1995b). He hypothesized that during evolution, because of their considerable adaptive significance, three neurocognitive systems, the Eye Direction Detector (EDD), the Shared Attention Mechanism(SAM), and the Theory of Mind Mechanism (ToMM) emerged. Instead of trying to identify the origin of these mechanisms in individuals, he emphasized the evolutionary, and the neurophysiological foundations of these mechanisms. He emphasized that the lack of joint attention behaviors among children with autism could be attributed to the dissociation between EDD and SAM, the former mechanism appears to be intact while the latter mechanism is impaired (Baron-Cohen, 1995a:43; 1995b).

These previous researches share another commonality in their general view about the nature of joint (visual) attention, namely, that joint attention is an aspect of individual ability, capable of being investigated independent of the caregiver. Tomasello pointed out that if we take seriously the notion of joint attention, we must stipulate the existence of two persons attending to the same aspect of their common environment. He emphasized the need of both participants being monitoring the other's attention to the outside entity as a true criterion for joint attention (Tomasello, 1995:106). He argues that the above implies an understanding of the other participant not as an object or capturer of attention or potential punisher, but as a person who intentionally perceives a certain aspect of the environment that is the same as one's own, or could be made to be the same (Tomasello, 1995:107).

However, even Tomasselo, who criticized all previous researches on joint attention for failing to recognize the underlying commonality among some of these skills, and for failing to recognize what he called the cognitive and social-cognitive bases of these behaviors has not gone beyond the individual infants, in the sense that he emphasizes the child's understanding of the adult's intention and not how the dyad as a system achieving the state of joint visual attention (Tomasello, 1995:124-125).

In this paper, we propose that the development of joint attention be examined from a dynamic systems point of view. We recognize the caregiver's intention to achieve joint attention even at the very beginning of her relationship with the infant. While a young infant has a very limited range of skills for interaction, the caregiver makes up a lot of the conditions necessary for achieving joint attention with the infant. She does different things according to the context of interaction and the developmental states of the infant. A full-blown joint attention only emerges from the dyad's overcoming first the spatial, then the temporal constraints, with the caregiver providing most of conditions first, and the infant taking over gradually. The purpose of this paper is to give an outline of the different phases of the development of joint attention, with an emphasis on the caregiver's scaffolding behaviors.

The Development of Joint Attention from Gaze Following to Conversation

Joint attention is a state of interaction which occurs frequently in everyday life.

Human social behaviors, particularly human communicative behaviors are basically based on the existence of joint attention among the participants. For example, when an object is handed to another person, or when an object is being referred to either by verbal expression or by fingerpointing, joint attention is a necessary condition for these acts to be meaningful. In these conditions, the target referred to does not have to be external physical object; it could be an idea or a concept. In conversation, when participants are commenting on the common topic(s), they are achieving a state of joint attention. The participants can achieve a state of joint attention even when one party has to be reminded of the existence or the relevance of an event, which was not in his/her mind up to that juncture. Indeed, as Bruner has pointed out recently, joint attentional episodes have a more general role in cultural popsychology (Bruner, 1995; Tomasello, Kruger, & Ratner, 1993).

If during conversation one feels that the other is not understanding what one is trying to convey, that is to say, when a sense of failure in achieving joint attention with the other is felt, we try to change the language we use, perhaps by using a different metaphor, or by adding hand gestures or facial expression, etc. in order to orient the other to what we have in mind. In this case, we make use of the context, the presupposition and/or knowledge that we have shared so far as Bruner also points out (Bruner, 1995:6). Joint attention, in its most sophisticated form, goes beyond gaze following to joint participation in a common culture. Through joint attention, we learn by imitating new behaviors from a more expert other, we deliberately teach the novice. Joint attention is an important base for cultural learning.

Thus, in order to achieve joint attention at a more sophisticated level, both participants have to monitor the attention of the other, and to judge if the other is orienting his/her attention toward the same target. However, because the target of joint attention is not limited to concrete external object, it is necessary to pay attention not only to where the other looks, but also the manner, the order and timing of verbal and nonverbal expressions of the other. With young infants who lack such subtle means of linguistic expressions, caregivers depend very much on their gaze, gestures, postures, and emotional expressions in monitoring and directing their attention.

Characteristics of Early Joint Attention

In the interaction between a young infant and his/her caregiver, a preliminary stage of joint attention is often achieved by calling the infant's name, or by bringing her own face into the infant's visual field. When the infant looks at the caregiver, then she may show a toy within the visual field. Because of the infant's limited capacity in controlling her own postures and her own attention, caregiver of young infants often make up these constraints for the infants in order to achieve joint attention with them. In this way, even with very young infants, far younger than what most researchers so far would acknowledge as being capable of joint attention, caregiver can achieve joint attention with them. As infants develop, the compensations a caregiver usually does in order to achieve joint attention also change.

When an infant can sit by himself and can control his attention by turning his head or body to whatever attracts him, the caregiver would use more distant modes of attention getting, such as speech voice or sounds produced by object. An older infant also begins to use pointing gesture or voice to object not visible by the caregiver to achieve joint attention. Thus, the caregiver compensate whatever elements are lacking in the interactional system in order to achieve joint attention with the infant. Viewed from this perspective, early joint attention is a property of the infant-caregiver interactional system, rather than the result of the development of the joint attention skills of the infant alone as implied by most previous researches.

Joint Attention From A Dynamic Systems Viewpoint

From the above discussion, it is clear that the development of joint attention can not be understood by merely describing the behavioral or cognitive changes of the infants. To understand the development of joint attention, it is necessary to understand how, owing partly to infant's developmental changes in action and perception, the infant and the caregiver change their behaviors and their roles in relation to the other, when monitoring and controlling the other's attention toward a common target.

According to the ecological view for development, 'the extraction of information that specifies the world is ever changing and that our understanding of this change demands attention to the structure of the organism doing the perceiving as well as the structure of the information to be perceived, with changes in either structure resulting in perceptual reorganizations' (Cooper, 1997:58). The same view can be applied to the development of joint attention. In the course of development, in order to achieve the state of joint attention, the caregiver and the infant constitute a dynamic system in which both the specification of the infant's body (length, weight, and flexibility of different parts, etc.), as well as the information perceived/perceivable change also, resulting in and causing changes and reorganization in both the caregiver and the infant's action and perception. Joint attention is not the result of the infant's skills, it is rather, a specific state of interaction of the dynamic system whose components include the infant and the caregiver in their various conditions. The following is an out line of a dynamic systems view of the development of joint attention in early infancy.

Development of Joint Attention in A Dyadic Interaction System

(1) Overcoming the Spatial Constraints

As a perceiver and an interactor, a young infant undergoes a variety of developmental changes, such as in his/her visual function, memory, understanding of causal relationship, and posture control (Tsuneda & Chen, 2001). Particularly in the early months, infant's posture imposes great constraint on the interaction with the caregiver (Rochat, 1992). In order to interact with an infant too young to maintain a sitting posture, for an example, the caregiver tends either to backup the infant with her hand(s), put the infant in a reclining chair for baby, or lay the infant on its side. In other words, the caregiver has to adjust her posture in order to be en face with the infant. At around two months after birth, an infant can visually focus at the caregiver in front of him, or at an object shown to him by the caregiver. However, it is not yet possible for him to shift his look from the one to the other flexibly. This is partly due to the immaturity of the infant's nervous system (e.g., Matsuzawa & Shimojo, 1997). Neverthless, the caregiver makes an effort to achieve joint attention with the infant by doing various things to 'make up for the infant'. The following is an episode from an observation carried out at the infant's home, which illustrates this point.

Episode 1: Ah, you're looking (2:14).

The infant was laid on a floor cushion (zabuton) supine, with his head turning to his left. The mother sat near his feet. She leaned over to look into his face.

Mother : " Morning, H. " She tried to make him look her way by calling his name. He moved his head several times, but was not looking at the mother.

Mother : " Here, this side! " She clicked her tongue. " Where are you looking? " The infant maintained looking to his left.

Mother : " H. Are you there? Look this side! " She tickled the right side of his cheek. " Mr. H.! " She called again. The infant made a small voice : " Ah-e. " She sat up and moved his feet from side to side.

Mother : " Time for exercise. One, Two, Three. " The infant remained looking toward his left. Mother stopped moving his feet.

Mother : " H. What are you looking at? What are there so attractive? " She peeked into his face, and extended her hand to reach for a rattle from a basket which was within his view. He looked at her arm which came into his sight.

Mother : " Here! " She shaked the rattle to attract him. He glanced at the rattle briefly, but turned his look back to the left side.

Mother : " H! It's here! " Touching the right side of his cheek with the rattle, she said sigingly. He now looked at the mother. She immediately leaned herself toward him and move her face and upper body toward the infant's right, as if trying to pull the infant to look at her.

Mother : " This side! This side! " He turned his head toward the right, and gazed at the mother. She shaked the rattle and he looked at the rattle briefly before looking at the mother's face.

Mother : " Ah, you're looking, aren't you? " She shaked the rattle. He Looked away from her, returning to looking to his left.

Mother : " Alah! " She uttered a voice disappointingly.

(2) Balancing the Sitting Posture and Manipulating a Toy

Around 4 months after birth, infants become able to hold their head steady and are frequently made to assume sitting posture when awake. This is because the sitting posture allows the infants a much wider visual field than was possible when lying supine, and this helps to keep the infants in good mood for a more extended period of time, and to facilitate play interaction with the caregivers. This is the beginning of the so called triangle relationship (i.e., infant, mother, and the object). Owing to being gradually liberated from the grip of the visual target in previous period, infants become able to choose the object of looking, and to manipulate what is in sight and within reach. In addition, the infants also enlarge their field of peripheral attention. However, they still need help to maintain in sitting position, especially when they are manipulating object.

To make up conditions for achieving joint attention with infant in this developmental state, the caregiver makes use of a variety of methods for attention getting, such as adjusting the infant's postures, touching the infant's cheek, lightly stroking one side of the body, calling the infant in melodious tone of voice, bringing her face up into the infant's visual field, using attractive toys or objects, and so on. Once the infant looks at the caregiver, she also tries to maintain and to extend this "window" available for interaction by continuing the attention getting acts and by introducting an object.

Episode 2 : It's hard to grab (4:29)

The infant was made to sit, with floor cushions around him to keep him from collapsing. He needed constant readjustment to maintain sitting. His mother was sitting on her heels on the floor in front of him. She was trying to get a toy with a string out from the basket on her side. The infant watched intently at her mother's movement, while holding a rattle in his left hand.

Mother : " Fancy it? This. " She dangle the toy in front of him. He looked at the dangling toy and, from time to time, shaked and licked the rattle alternatively. The mother tried to attracting his attention by keeping the toy dangling. He banged the floor with his hands, with a tense expression and a frown, as if he was angry.

Mother : " Eh! " She uttered a sound, imitating the infant's expression, while she kept dangling the toy in front of him. He waved his arm with effort, unable to reach the toy. His upper body tilted.

Mother : " Eh? Are you all right? Not comfy? " She helped him sit up. she showed the toy again. He waved his arm with effort. Failing to reach the toy he threw the rattle on the floor. The mother moved the toy to him and touched his hand. Now he caught the toy and put it to his mouth and licked it.

Mother : " You gobbled it. " She pulled the toy up away from his mouth and dangled it in front of him. He caught it again and put it into his mouth again.

When the infant begins to follow the caregiver's movement actively and to focus on the object she is showing him, the first form of joint attention can be said to be achieved. With this, the caregiver's role in achieving this interactive state also changes. The caregiver is not only getting the infant's attention to the object she is showing, she also tries to monitor and direct his attention to how the object is to be manipulated, all at the same time. As was shown in the above episode, the mother sat the infant in a sitting position, maintained his posture by floor cushions, dangled the toy, vocalized, pulled the toy from his mouth, and touched his hand with the toy. In doing all these, two things are being achieved : (1) the caregiver extends the time frame of joint attention from a brief one of the infant looking either at the caregiver or the object, to a longer frame in which the attention of the infant shifts from the one to the other, often alternatively, (2) the caregiver conveys the structure of joint attention as being framed within the triangle relationship. The latter is usually achieved by the caregiver's differential expressions of looking; the 'attention getting' looking at the beginning, and the 'semi-intersubjective' looking after she makes sure that the infant seems to understand what she means and that she knows this. Nevertheless, infants around 6 months of age are still in a stage where they can only look at either the caregiver or the object, one at a time. The caregivers also tend more frequently to elicit from their infants what Tomasello called "gaze alternation" (Tomasello, 1995). In addition, owing to infants' development in memory retrieval, infants at this age are beginning to be seen shifting their gaze suddenly to a different direction, as if they are being reminded of something else than what they are engaged in. Caregivers tend to interpret this behavior as infants' intention to express something, as illustrated in the following episode.

Episode 3: You want to say something? (5:13)

The infant was sat on an air cushion for children, while his mother sat in front of him, en face. The observer was video-recording their interaction in profile view.

The mother tried to wipe the infant's mouth with a towel, but the infant avoided her by turning away and hitting the air cushion as if in protest.

While his face was being wiped, he looked at the camera and the mother from time to time. When she stopped wiping his face, the infant looked intently at the camera, with no movement nor vocalization. As the look was very intense, the observer chuckled. The infant looked at the observer and turned toward her with a smile, hitting the air cushion several times, as if he was happy about the observer's chuckling comment on his hitting.

Mother : " That bothers you most, doesn't it. The camera. " She was talking to him. Then he looked at her, not smiling. She looked at him and said " Ah! " He then also uttered " Ah! " and hitting the cushion with his left hand, as if he is responding to the mother's vocalization.

Mother : " Ah! You understood, eh? " She looked into his face. He looked away and vocalized " Ahn! " The mother imitated him. He looked at her and repeated the vocalization " Ahn! "

Mother : " Ahn, ahn, ahn. " Repeating the voice and nodding, she took his hands in hers and brought her face near him.

Mother:" You want to say something? Tell me! What's in your mind? " She talked to him softly. He then turned his face toward the observer, smiling, and said " Eh, eh. " The mother imitated the infant's vocalization while making another attempt to wipe his face with a towel.

In this episode, the infant first showed an interest (concern) in the camera and the observer by looking intently at them, and at the mother from time to time. The caregiver was watching at all this. A state of joint attention can be said to have been achieved by the caregiver and the infant. Furthermore, the joint attention then led to the caregiver's interpreting the infant's behavior as showing an intention for expression.

(3) Extending the Interaction Window

When mutual gazing becomes available more frequently, the the caregiver begins to extend the window for interaction by immediately changing her behavior from attention getting to object manipulating. This is often carried out within a zone very near her face, with constant monitoring of the infant's attention, as seen in the next episode.

Episode 4:Ahoy! Here It Goes! (12:26)

Mother sat on her heels at the center of the room, and the infant stood by her.

The observer was about 2m away from them, facing the mother. The infant looked at the observer, with concern. The mother put a piece of building block into a cylinder and shaked it, producing a rattling sound to attract the infant. Upon hearing the sound, the infant turned back and looked at the cylinder. The mother tilted the cylinder and let the block piece slide down the cylinder toward the infant. The infant looked at the block piece, picked it up and put it back into the cylinder, and looked at the observer. The mother repeated the tilting act, uttering something. The infant looked back toward his mother and stared at the building block. He took it out of the cylinder and then put it back.

Mother : " Ahoy! Here it goes! " She tilted the cylinder and let the block piece slide toward the infant again.

Mother: " There it goes again! " When this was repeated once more, the infant cried out " Ah! " and looked to the observer. The building block fell on the floor.

Mother : " It dropped! " The infant looked at the block piece on the floor and picked it up. She asked the infant to put it back, and he diso.

Mother : " Look! " She tilted the cylinder toward herself. The infant looked at her, expectingly. Mother " It came this way. This way. " She then tilted it toward the infant and said " There! " They repeated this sequence four more times.

(4) Overcoming Temporal Constraints:Attending to Past Event

Most infants older than 12 months are self-locomotors, their ability in posture control allows them to orient to stimulus of interest actively. They are also able to monitor their caregivers' attention during interaction. While for the infants, gaze has been a means of looking (gaze as perception), now it assumes the new meaning of expression (gaze as communication).

Episode 5:Bidding farewell (14:21)

The mother sat on her heels at the center of the room. The child stood by her. They had been reading a picture book together. The child walked away from his mother with the book toward one corner of the room where he put the book into a handbag on the floor which belonged to the observer.

Mother : " Want to put it away? You do. Then, there! " The child looked at her.

Mother : " Right?! " They gazed at each other. The child began to take the book out of the handbag.

Mother : " Don't get the other thing out. " She was monitoring what he did.

Mother : " Have you got it? Have you? " He was not being able to get the book out. She moved near the child to help. " There you are! " He received the book and thrusted it back to the handbag. He tried to get the book out again, while gazing at the mother.

Mother : " Have you got it? " She took the book out of the handbag and gave it to him saying " Here you are. " He took it and again put it back.

Mother : " You did it again. Oh, no! Let me get you a different bag. " She left for the

next room. He touched and groped about the handbag.
Mother : " There you are! Your bag. Put it in here. " He gazed at the new bag.
Mother : " In it goes. The tramcar (book) in here. " She pointed at the book. The child looked at the book and took it. She opened the bag and made it easy for him to put the book in. He looked at the bag but no action. Instead, he took a pockbook out of the bag.
Mother : " There it goes. I did it. " She put the book into the bag. He looked at all this and then put the pockbook into the bag.
Mother : " Want to put the phone? The mobile phone? " She put the toy phone in. He looked at the mother's hand movements.
Mother : " There! Want me to put it on your shoulder? There! " She put the strap across his chest. He smiled and began to walk about.
Mother : " Itterasshai! " She pretended the farewell-bidding ritual playfully. The child walked about the room and found a toy car at one corner and began to play with it. Mother: " Do you go with your car? " He put down the toy car and walked about. Mother:" Itterasshai! " She waved her hand to him. He looked at her and then walked toward the entrance. He tried to open the door leading to the entrance. Mother:" You really want to go out, eh? " He tried hard at opening the door. Mother " Want to open it? O.K. " She moved near to the door and opened it for him. He passed the door and walked toward the entrance and gazed at the shoes. He then turned around slowly and walked back to the room saying " Damma, (I am home) " raising his hand, smiling. He looked at the observer and the mother much pleased. Mother:" Welcome home! " She gazed at the child and smiled.

Some Theoretical Hypotheses

(1) *The Primacy of Looking.*

Joint attention begins as an unconscious act of the caregiver in seeking eye contact with the infant. A caregiver constantly monitors the state of the infant. When the infant is awake and quiet, she either leaves him alone, or she interacts with him, by talking to or looking at him. When the infant is awake but fussing or crying, she tries to alter his behavioral state by holding him up or getting his attention by calling his name or showing her face. The first stage of joint attention is achieved by the caregiver getting the visual attention of the infant. She is satisfied by the infant's looking at her, no matter how fleeting the mutual gaze is. Although the gaze of the caregiver does not seem to generate much emotional excitement in the infants during the first weeks, at two months, it elicits social smile form the infants. This smiling response of the infant further encourages the caregiver to keep eliciting the response from the infant in later months. Although looking remains important for mutual understanding for the rest of one's life, a sophiscated form of joint attention goes beyond the visual mode. The primacy of looking in joint attention can better be appreciated by examining the development of joint attention behaviors in dyads with deficits in visual function.

(2) *Spatial and Temporal Constraints.*

There are spatial and temporal constraints the infant-caregiver interaction system has to overcome in order to achieve joint attention. The spatial constraints arise from the infant's limitation in controlling his posture and in maintaining attention on a target. During the early months, visual attention can only be achieved within a relatively narrow cone-shaped zone, projecting from the infant's upper body. The caregiver plays an important role in making sure that the target of attention is posited within this zone. This zone enlarges as infant develops. The caregiver varies what she does as this zone changes. The caregiver sometimes has to fall back to an earlier strategy, if the system's conditions are being compromised by the infant's emotional states, such as fussiness or drowsiness.

The temporal constraints arises from the limitedness in infant's memory and knowledge. However, as infant develops, the 'here-and-now' mode extends to include the past and the future (Donaldson, 1985). The extension of the infant's mode of operation benefits from engagement in narrative activities with the caregiver (Siegel, 1999:60-64). How the caregiver first cope with, then extend, the infant's limitedness in the mode of operation need to be uncovered before the achievement of joint attention can be more fully understood.

The details of the caregiver's strategies in first overcoming the spatial, and then the temporal constraints in achieving a more sophiscated form of joint attention will reveal the processes of the system in constructing a fuller mutual understanding. The behavioral sequences of interaction between the caregiver and the infant should provide clues for designing better programs in helping dyads with special needs.

(3) *Beyond Gaze Following.*

In research literature, the term 'joint attention' has been used in a loose way, ranging from meaning the gaze following behavior(gazing as perception) to a more sophisticated form of joint attention with intersubjectivity.

The same gaze following behavior can sometimes have the meaning of mutual understanding (gazing as expression/communication), especially when the gaze to the target is further followed by a look back to the directing face, and with a smile of understanding. Although children with autism are said to be able to follow the direction of other's gaze, it is rarely that they further look back to the directing face, let alone doing so with a smile (Beppu, 2001).

Conclusion

Joint attention, considered from a process (developmental) point of view, consists of behaviors of both the caregiver and the infant. It first appears as the caregiver's intention to obtain visual attention from the infant. In the early months, caregiver has to do most of the monitoring, positioning, attention getting, extending the window of attention, manipulating, and distancing the object from herself. In other words, the first task for the caregiver is to overcome the spatial constraints of the interaction system. In subsequent months, when joint attention begins to take place away from the 'here and now', with invisible target becoming the focus of attention, the dyadic interaction system is said to have overcome the temporal constraints, entering the realm of a more sophisicated joint attention, which is the hallmark of genuine human mutual understanding, as celebrated in many literary works.

By approaching joint attention from a dynamic systems perspective, not only important concrete research questions can be formulated, theoretical hypotheses can also be generated, thus leading to a bettering understanding of the process of its development.

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AGE-RELATED CHANGE IN JAPANESE MATERNAL INFANT-DIRECTED SPEECH AND INFANT'S VOCAL RESPONSE

Katsuko Niwano & Kuniaki Sugai
Tohoku University

Abstract

We have investigated how maternal infant-directed speech shows age-related change, and which acoustic features of maternal infant-directed speech elicit an infant's vocal response effectively during the prelinguistic period. Voice samples of 50 Japanese mother and infant dyads were recorded during the first 9 months of the infant's life longitudinally. Fundamental frequency (f_0) from the mother's speech and the infant's vocalization during mother-infant interaction were extracted and analyzed using an acoustic analyzer. The acoustical features measured in this study were the mean f_0, f_0-range, and the intonation contour. We found age-related change in the prosodic features of mother's speech. The mothers changed f_0 in their infant-directed speech during months 3-5, and 7-9 postnatally, and they changed f_0-range during months 5-7 postnatally. They showed a falling pattern of intonation contour most frequently during age 3 and 7 months and a rising pattern appeared most frequently at the infant was 9 months old. The infant's response also showed age-related change. Three-month-old infants tended to respond to the maternal speech with any value of f_0 and f_0-range. In contrast, 9-month-old infants tended to respond to the speech with higher f_0, more exaggerated f_0-change, and a rising pattern of intonation contour selectively: The results suggest that the change in acoustic features of maternal speech reflects the infant's perceptual and linguistic development.

Key Words : mother-infant vocal interaction, infant-directed speech, infant, prelinguistic period, acoustic analysis

Introduction

Numerous attempts have been made by psychologists and linguists to show the characteristics and the roles of maternal speech to infants. There are many differences between infant-directed speech and adult-directed speech. When mothers talk to their infants, the melodic and rhythmic qualities of maternal voices are exaggerated (Fernald & Simon, 1984; Fernald, Taeschner, Dunn, Papousek, DeBoysson-Bardies, & Fukui, 1989; Grieser & Kuhl, 1988; Papousek & Hwang, 1991; Shute & Wheldall, 1989). Mothers use higher pitch, a greater pitch range, slower tempo, longer pauses, shorter phrases, higher

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We express appreciation to all the mothers and their infants who participated in this research and to the staff of Public Health and Welfare Center, Izumi Ward Government Office, Sendai, who helped with the recruitment of participants. Correspondence concerning this article should be addressed to Katsuko Niwano, Graduate School of Education, Tohoku University, Kawauchi, Aoba-ku, Sendai 980-8576 Japan. E-mail:niwano@riec.tohoku.ac.jp

exaggerated pitch contour, and more prosodic repetition compared to their speech to an adult (Bergeson & Trehub, 1999; Fernald & Simon, 1984).

One of the roles played by maternal infant-directed speech is apparently the regulation of arousal and attention in infants (Cooper, Abraham, Berman & Staska, 1997). Mothers try to maintain infants' attention and positive affection by using infant-directed speech which is characteristic phonetically (Bergeson & Trehub, 1999; Trainor, 1996; Trainor, Clark, Huntley, & Adams, 1997). Newborns show preferences for the maternal voice over an unfamiliar female's voice (DeCasper & Fifer, 1980; Fifer & Moon, 1995). Fernald (1985) found that 4-month-old infants chose to listen more often to infant-directed speech than to adult-directed speech. This preference appears to be consistent throughout the first year of life (Fernald & Kuhl, 1987). Infants start to produce utterances in response to maternal speech to them from early in life (Masataka, 1992).

This brings us to the question as to which acoustical features infants pay attention. Niwano & Sugai (2001, 2002) reported the acoustic features of maternal speech and 3-month-old infant's utterance during mother-infant interaction. One of the important findings in the studies is that intonation contour is the most effective means to elicit 3-month-old infant's vocal response in acoustic features of maternal infant-directed speech, and that a 3-month-old infant responds to the maternal speech which is terminated with a falling contour more than other contour types. As Fernald and Simon (1984) pointed out, infants prefer to listen to the intonation contour of maternal speech, and the intonation patterns of maternal infant-directed speech may be perceptually salient to the infant. Powers (2001) reported that infants are sensitive to prosodic features of adult vocalization.

However, few attempts have been made to date to elucidate the age-related change in maternal infant-directed speech. It is known that during the first year after birth, infants show radical developmental change. We should notice that the prosodic features of mother's speech might show change consistently in the prelinguistic period and some changes in maternal infant-directed speech might relate to the development of the infant's communication ability and biological maturation. More noteworthy is that which acoustic features infants respond to might also change according to development. Although Fernald (1992) pointed out that infants have predispositions innately to respond selectively to characteristic features of maternal infant-directed speech, the selection might change through the infant's prelinguistic period. Therefore we need to discover details of normal communicative development occurring within the prelinguistic period and how a mother communicates with her infant. This offers a key to understanding how the ability of communication develops, and it would contribute to early detection and early intervention for the children with a communication disorder.

The purpose of this study was to investigate how maternal infant-directed speech shows age-related change, and to determine which specific acoustic features of maternal speech elicit the infant's vocal response effectively during the first 9 months after birth. In the present study, we focused on three acoustic features: fundamental frequency (f_0), f_0-range, and intonation contour. The reason why we chose these three acoustic features is as follows. First, f_0 is the most salient of the prosodic components in infant-directed speech (Katz, Cohn, & Moore, 2000). Second, one of the characteristics of maternal speech is exaggerated f_0-range (Katz, Cohn, & Moore, 1996). Third, intonation contour is considered to most define infant-directed speech (Bergeson & Trehub, 1999). We carried out an acoustic analysis and extracted these three acoustic features from the voice samples of mother-infant interaction and analyzed them in detail.

In many previous studies on maternal infant-directed speech, the researchers regarded that f_0-range equaled the difference between the maximum and minimum values of f_0 for each speech, and utilized 'Hz' as an f_0-range unit. However, human perception of f_0-range should be calculated logarithmically in general, so we utilized 'semitone' (12 semitones = 1 octave) in this study. In addition, the sample size has not been an issue in almost all studies on mother-infant vocal interaction. However, a large number of samples are needed to obtain universal data. Thus, our study was conducted on 50 mother-infant dyads in longitudinal samples of infants ranging in age from 3 to 9 months.

Method

Participants

Fifty Japanese mothers and their infants composed the final sample. The infants were firstborn, born in 1998-1999, 25 males and 25 females. All of the mothers were full-time housewives (*M* age at child birth = 29.3 years, *SD* = 4.3 years), primarily drawn from the middle socioeconomic classes and native-born citizens of Japan. The data were collected during home visits when the infants were 3, 5, 7, and 9 months of age. All of the infants were healthy with no history of hearing disorder or infection. An additional 4 infants failed to complete the recording because of excessive crying (2), and little utterance (2).

Procedure

Utterances by the mother-infant dyad were tape-recorded. A high-quality microphone (Sony ECM909) was connected to a portable, audio cassette recorder with automatic gain control circuitry (Sony TCS90) and set on a table in the home. The microphone was set on a table about 1 meter away from both the mother and infant. The mother was instructed to talk to her infant as she normally did at home. Each recording session lasted 15 minutes. Both the mother and the infant were seated on a chair or on the floor facing each other. Then, we sampled 3 consecutive minutes, selecting them so that the vocal interaction of mother and infant included many utterances and the least noise. To compare the mother's infant-directed speech with her adult-directed speech, the conversation between mother and experimenter was also recorded for 5 minutes at home. We sampled the last 3 minutes in the 5-minute recording.

Following Stern, Spieker, & MacKain (1982), a sequence of maternal infant-directed speech which did not include any pause exceeding 0.3 sec was defined as one utterance. All meaningful communicative vocalizations were considered as words, e.g., agreeable sounds such as *ooh*, *aah*, and *mmm*. Whispered and partially whispered utterances, songs, and nonverbal sounds such as kisses, and laughter were excluded. Following Masataka (1992), when an infant vocalized within 3.0 seconds after the end of maternal infant-directed speech, the utterance was counted as a response.

Acoustic analysis

Two skilled coders acoustically analyzed the three-minute speech samples. One of the coders was an author of the present study and the other was blind to the purpose and hypotheses of the present study. Inter-coder concordances: measurement fundamental frequency (f_0), duration of pause, and categorization intonation contour type, were presented with high reliability (.94, .95, .98). For cases in which there was disagreement, the data were excluded. They used Multi Speech 3700 (Kay Elemetrics), which is software for acoustic analysis and allows measurement of f_0 and duration of utterance and pause. Analysis of f_0 was performed with narrow-band analysis (29 Hz) and frequency scale up to 2000 Hz (sampling rate = 10000 Hz).

Dependant Measures

Mean f_0

A mean f_0 is an arithmetic mean of start frequency, end frequency, maximum frequency and minimum frequency of one utterance. Multi Speech 3700 is allowed to computerize statistically a mean f_0 of each utterance, but it was not appropriate in the present study because the mother's utterance was sometimes overlapped by the conversational partner's utterance.

F_0-range

An f_0-range is measured logarithmically as the distance in semitones between f_0-minimum and f_0-maximum for each utterance.

Classification of intonation contour

Previous studies have shown that the typical intonation contour of the infant-directed speech can be classified according to the extent and direction of the f_0 excursion (Fernald & Simon, 1984; Griesern & Kuhl, 1988; Masataka, 1992; Stern, Spieker, Barnett & MacKain, 1983; Stern, Spieker & MacKain, 1982). Five of the most common intonation contours were identified by Stern, Spieker & MacKain (1982): sinusoidal (up-down-up or down-up-down); bell (up-down); bell right (slight up-large down); rise (up); and fall (down). We classified the seven intonation contours of all voiced maternal speech into three groups concentrating on the terminated intonation contour, comparable to those described by Papousek, Papousek, & Haekel (1987). Garnica (1977) noted the function of the terminal contour of sentences uttered by adults when they spoke to children. Sugito (1994) observed that the partner's terminal falling contour gave another partner cue timing for response during adult-adult conversation in Japanese. Therefore, it seems that the terminal contour is the predominant part of the contour compared to the initial or middle part in a whole utterance.

The first group of terminal pitch movement is falling, the second group is rising, and the third group is flat with no shift in the direction of pitch movement. Each of the groups of falling and rising includes three types of contours: The falling group includes (1) unidirectional falling, (2) bell-shaped (up-down) contours, and (3) complex sinusoidal contours with two or more shifts and is terminated with falling. The rising group includes (1) unidirectional rising, (2) U-shaped (down-up) contours with one shift, and (3) complex sinusoidal contours with two or more shifts, and is terminated with rising. Following the study by Fernald & Simon (1984), a minimum f_0 excursion of 6 semitones/s (12 semitone = 1 octave, which is calculated logarithmically) was a defining characteristic of all contour-types in the present study.

Results

Mean f_0 and f_0-range

The total numbers of mothers' analyzable utterances, overall mean f_0, and average f_0-range every postnatal month of maternal infant-directed speech and maternal adult-directed speech were presented in Table 1. Comparing the mothers' infant-directed speech with their adult-directed speech, all of the features (i.e., number of utterances, overall mean f_0, and average f_0-range) were higher in infant-directed speech than in adult speech. Inter-infant-directed speech, the number of utterances decreases at 5 months, but increases after 7 months. Both of overall mean f_0 and average f_0-range increase from 3 to 9 months of age. To determine the difference of overall mean f_0 and average f_0-range between age groups: the data of 3 months and 5 months, the data of 5 months and 7 months, and the data of 7 months and 9 months, were statistically ana-

TABLE 1 Mean f_0 and mean f_0-excursion of infant-directed speech and adult-directed speech. The numbers in parentheses in the line of mean f_0 and mean f_0-excursion indicate standard deviation.

	Infant-directed speech				Adult-directed speech
Infant's age (month)	3	5	7	9	
Number of utterances	2908	2501	2731	2963	1527
Mean f_0 (Hz)	301 (77)	312 (65)	317 (72)	329 (81)	208 (53)
Mean f_0-range (semitone)	7.2 (5.5)	7.9 (4.3)	8.9 (5.7)	9.6 (6.2)	6.6 (2.4)

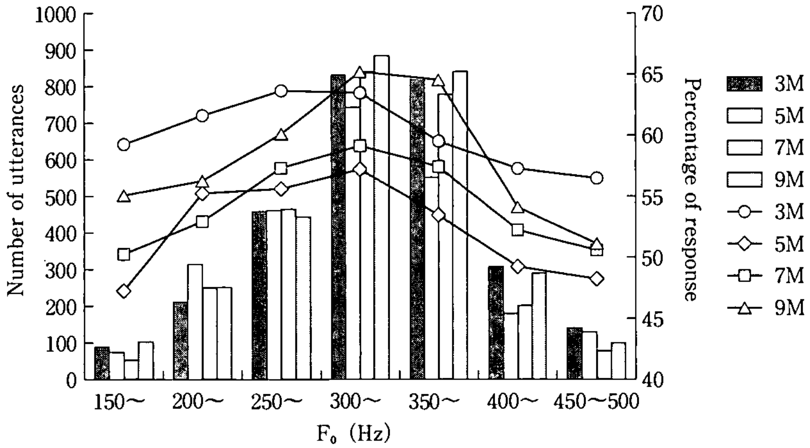

Figure 1 The bar chart indicates the number of maternal infant-directed utterances at each section of every 50 Hz of f_0. The line graph indicates the percentage of infant's vocal response to each f_0 section of maternal infant-directed speech.

lyzed by Student's t test. There were significant differences of average of mean f_0 between 3 and 5 months, and 7 and 9 months (t = 1.66, t = 1.67, all ps $<$ .01, respectively), and average of f_0-range between 5 and 7 months (t = 1.84, p $<$ .01).

Fig. 1 shows the number of maternal infant-directed utterances at each section of every 50 Hz of value of f_0. The utterances that were more than 500 Hz existed in each month group, but they were omitted them from the chart because the number was less than 20. The rate of 5-, 7-, and 9-month-old infant's response to maternal speech highly

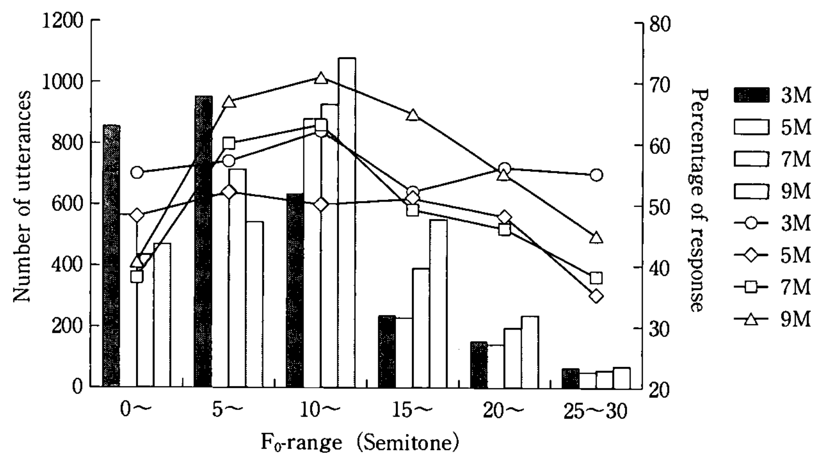

Figure 2 The bar chart indicates the number of maternal infant-directed utterances at each section of every 5 semitones of f_0-range. The line graph indicates the percentage of infant's vocal response to each f_0-range section of maternal infant-directed speech.

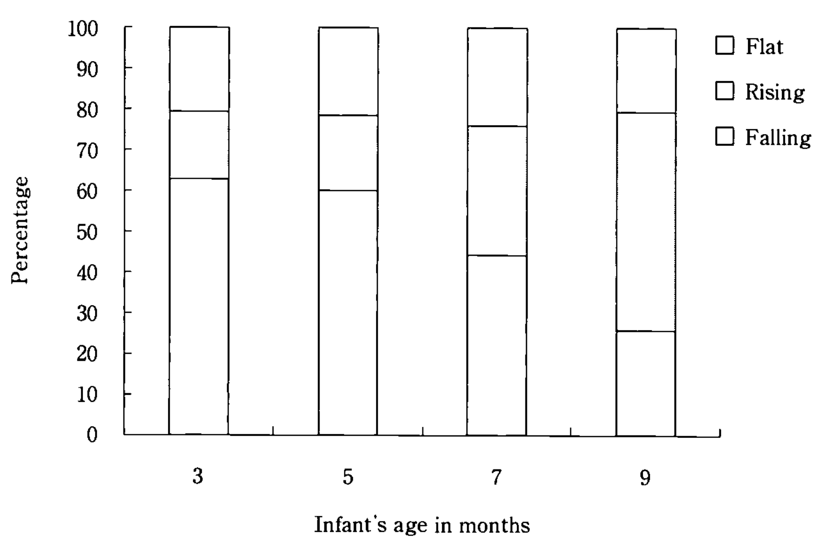

Figure 3 Percentage of appearance of each intonation contour pattern of maternal infant-directed speech according to infant's age.

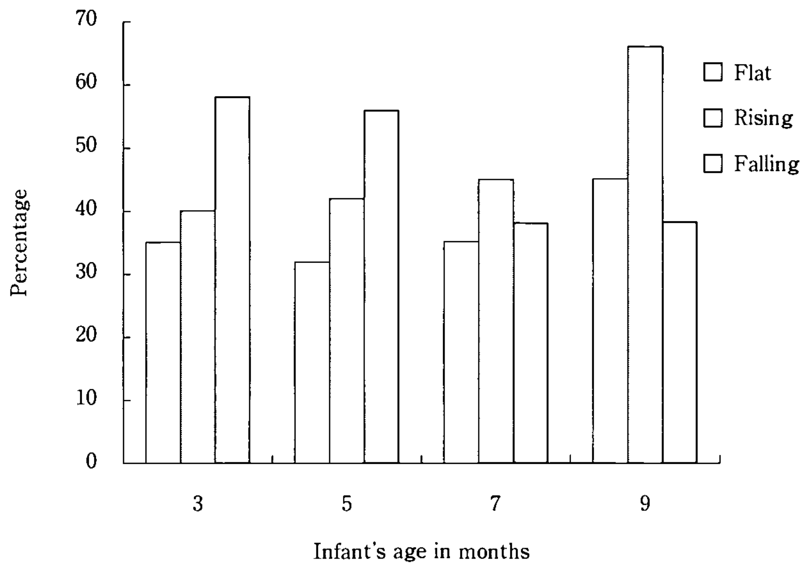

Figure 4 Percentage of infant's vocal response to each intonation contour pattern of maternal infant-directed speech according to infant's age.

correlated with the number of maternal speech in each 50 Hz section (r = 0.89, r = 0.95, r = 0.95, all ps < .001, respectively).

Fig. 2 shows the percentage of infant's vocal response to each f_0 section of maternal infant-directed speech. The utterances which were more than 30 semitones existed in each month group, but were eliminated them from the chart because the number was less than 20. The rate of 7-month-old infants' response to maternal speech significantly correlates with the number of maternal utterances in each 5-semitone section (r = 0.86, p < .005).

Intonation contour

Fig. 3 shows the rate of appearance of intonation contour patterns of maternal infant-directed speech according to infant's age. The intonation contour pattern that appeared most often in the maternal infant-directed speech was the falling contour from 3 to 7 months, but it decreased steadily. On the other hand, the rising contour increased steadily from 3 to 9 months of age. At 9 months, the rising contour appeared most often.

Fig. 4 shows that the rate of infant vocal response to the maternal speech with each intonation contour pattern. Intra-pattern differences of the rate of infants' response in each month of age were analyzed by the Kruskal Wallis test. There were significant differences among the rate of infants' response to the three patterns of intonation contour uttered by their mothers at 3, 5, 7, and 9 months ($\chi^2(2)$ = 15.21, $\chi^2(2)$ = 13.62, $\chi^2(2)$ = 9.34, $\chi^2(2)$ = 15.81, all ps < .001, respectively). The infants responded to the maternal speech with the falling contour most frequently when they were 3 and 5 months old, then did to the speech with the rising contour most frequently when they were 9 months old.

Discussion

Mean f_0 and f_0-range

Mothers were found to change their mean f_0 and f_0-range when they spoke in terms of the infant age. For 3-month-old infants, the mothers tended to speak with lower mean f_0 and f_0-range, similar to their adult-directed speech. Then the mothers kept on changing the quality of their speech steadily to a higher mean f_0 and expanded f_0-range. However, it seems reasonable to suppose that the rate of the 3-month-old infants' vocal response was not influenced by f_0 value and f_0 range of maternal infant-directed speech. On the other hand, at 7 and 9 months, the infants displayed selective response to the maternal speech with a specific f_0 value and f_0-range. They tended to respond to maternal speech with mean f_0, which was between 300 and 350 Hz, more frequently than other maternal speech of f_0 value. They also tended to respond to the maternal speech with f_0 -range, which was 10 to 15 semitones more than maternal speech with another f_0-range level. The maternal speech with 300-350 Hz and 10-15 semitones frequently evoked the infants' response. Also, such speech was uttered by mothers often. Given that infants tended to respond to the most familiar value of mean f_0 and f_0-range, we can explain why there were significant correlations of the rate of infant's response with the number of maternal utterances in each section of the mean f_0 and f_0-range.

Garnica (1977) found that higher pitch is unique to a social function and that it attracts the child's attention to verbal material directed to him. In the present study, the infants showed age-related change and more response to the maternal speech with higher f_0 and grater f_0-range after 3 months, possibly reinforcing the mothers' habit of speaking with higher f_0 and greater f_0-range. It seems like a newborn infant may have universal sensitivities and may respond to any phonetic variation in speech signals. But after 3 months, infants learn certain specific function of phonetic features and show selective response.

Intonation contour

The intonation contour pattern of maternal infant-directed speech also was changed from 3 to 9 months of age. With each month, there was a significant difference in an infant's response. This means that the discrimination of intonation contours depends on the infant's age.

The infants showed the highest rate of response to maternal infant-directed speech with the falling contour at 3 to 7 months of age, but the response to the falling contour was decreasing; on the contrary, the response to rising contour was increasing and it showed the most frequent response at 9 months. A possible reason why 3- to 7-month-old infants responded to the falling contour more than other contours may be that they had become more familiar with the maternal infant-directed speech terminated with the falling contour than the other contour types because the falling contour occurred most frequently in maternal infant-directed speech. This tendency presumably reflects the appearance of intonation contour in the maternal speech. Most of the maternal nodding and agreeable responses (e.g., hi (yes), so (is that so?), ooh, aah, and mmm) were uttered with the falling contour. According to Sugito (1994), more agreeable responses appear in a Japanese conversation than in may other languages, and they tend to terminate with the falling contour. She pointed out that what a partner responds to is the terminal intonation with the falling contour in Japanese conversation. We suggest that the agreeable response in this case serves to elicit the infant's response.

On the other hand, the rising contour tended to be used as question (e.g., 'Are you having a good time?') or request (e.g., 'Can you pass me the toy?'). Therefore the speech with rising contour might serve to encourage an infant's response, and rising terminals might cue the infants in timing their response. Mothers reportedly use rising contour for encouraging a visual or vocal turn (Fernald & Simon, 1984: Stern, Spieker, & MacKain, 1982). Papousek, Papousek and Symmes (1991) suggested that mothers seem to mark opening, continuing, and closing interaction using rising or falling contours. As long as infants are not able to control their own communicative turns, mothers establish a framework of turn taking (Kaye, 1979). We suggest that infants learn the function of a rising contour in context through interaction, and their response to the rising contour gradually increases until 9 months. We can be fairly certain that mother's speech facilitates communication learning, and that change in the pattern of maternal speech is a way of adjusting to the infant's developing understanding of the role of intonation contours.

General discussion

Undoubtedly, rich mother-infant interaction is important for an infant's normal development. Vocal interaction between mothers and prelinguistic infants is an important step in the acquisition of communicative skills for infants, and these skills lead eventually to the acquisition of language (Masataka, 1992). It is also important for a mother to interpret what the infant wants to express with vocalization through interaction. The mother's interpretation awakens the infant to a social awareness of his/her own vocalization (Shimura & Imaizumi, 1995). The developmental stage of the infant's vocal response and the infant's biological development deserves closer investigation. Aitken and Trevarthen (1994, 1997) found that the neural system for providing the motivation for intersubjective communication is already formed in the brain of the human fetus. Therefore infants have an innate motivation to communicate. They are thus born to communicate and to learn (Powers, 2001).

Before birth, all the neurons are formed, but head size, brain weight, and thickness of the cerebral cortex continue to grow rapidly in the year after birth. Synapses in the infant brain continue to develop after birth and peak in number between 9 months and 2 years. Metabolic activity in the brain reaches adult levels by 9 to 10 months. Therefore infants show the turning point of language development around 8 or 9 months (Bate, Thal, & Janowsky, 1992), when they start active, spontaneous communication. This accords well with much of the data in the present study. One reason for an immediate sharp increase in response for certain specific acoustic features particularly at 9 months in the present study is that infants then achieve the turning point in the maturation of their neuro network and physiological change.

Another biological maturation is needed for vocal communication. The shape of the human vocal tract seems to have been modified for the demands of speech during the year after birth (Pinker, 1995). When the infant reaches around 5 months, he/she starts to utter canonical babbling. During 3-5 months after birth, the infant's vocal tract changes physiologically. The larynx slides down and the pharynx extends. It is a modification for the demands of speech. Thus, the quality of an infant's voice changes very much during the pre-linguistic period. The change in the mother's prosodic features might also reflect the infant's anatomical development.

Mother serves a primary function in facilitating the increasing communicative vocalizations and language learning. Mothers and infants influence one another and develop mutually. The mother's use of appropriate infant-directed speech in accord with the infant's developmental level of maturation of the neurons, metabolism and vocal tract is an effective means to facilitate the infant's communication ability.

Conclusion

The present study led us to the following conclusions: (1) Maternal infant-directed speech shows age-related change in the prosodic features during the first 9 months of infant life. (2) Mothers change the f_0 in their speech during months 3-5, and months 7-9 of postnatal life. (3) Mothers change the f_0-range during months 5-7. (4) Mothers produce a falling pattern of intonation contour most frequently during the first 3 to 7 months, and the rising pattern appears most frequently at 9 months. (5) The infant's response also shows age-related change. (6) Three-month-old infants tend to respond to any value of f_0 and f_0-range. (7) Nine-month-old infants tend to respond to higher f_0, and more exaggerated f_0-change. (8) Three- and 5-month-old infants tend to respond to a falling contour more than other contour patterns. (9) Seven- and 9-month-old infants tend to respond to a rising intonation contour more than other contour patterns.

These results suggest that infants learn certain specific functions of phonetic features and show selective response. On the other hand, the change in an infant's response to each maternal infant-directed utterance with different acoustic features depends on the infant's physiological development. We may, therefore, reasonably conclude that mothers modified their use of acoustic features and pattern of intonation contour for the infant's perceptual and linguistic development during the first 9 months.

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MEASURING HUMAN FETAL RESPONSES TO SOUNDS BY UMBILICAL AND MIDDLE-CEREBRAL ARTERY VELOCITY WAVEFORMS: A PRELIMINARY STUDY

Kiyobumi Kawakami
University of the Sacred Heart
Kiyoko Takai-Kawakami
Japan Women's University
Naoe Masuda
Keio University
Makoto Suzuki, Yukiko Shimizu, Takumi Yanaihara
Showa University

Abstract

The most common measures of human fetal auditory perception are heart rate and fetal movement using an ultrasound scanner. In this study human fetal responses to two kinds of sounds (white noise and Japanese drumming) were measured by umbilical and middle-cerebral artery velocity waveforms using an ultrasound pulse Doppler unit. The sounds had an effect on umbilical artery velocity waveforms. We will be able to use umbilical artery velocity waveforms as new and sensitive indices of human fetal responses to sounds.

Key Words : Fetus, response to sounds, Umbilical and middle-cerebral artery velocity waveforms, attention

Introduction

According to several reviews (e.g. Kisilevsky, 1995 ; Kisilevsky & Low, 1998; Lecanuet, Granier-Deferre, & Busnel, 1995; Querleu, Renard, Boutteville, & Crepin , 1989), the most common measures of human fetal auditory perception are heart rate (HR) and fetal movement using an ultrasound scanner. In this paper we introduce indices new to developmental psychology, but already widely used in obstetric research (Fleischer, Schulman, Farmakides, Bracero, Blattner, & Randolph , 1985 ; Noordam, Hoekstra, Hop & Wladimiroff , 1994 ; Wladimiroff, 1994) : umbilical artery velocity waveforms (UAVW) and middle-cerebral artery velocity waveforms (MAVW) measured by an ultrasound pulse Doppler unit (see Figure 1). The analysis of UAVM has been a useful,

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We would like to thank Dr. Mary Blish, Dr. John Nesbit, Dr. Barbara S. Kisilevsky, Dr. Roy T. Nakayama, Ms. Eriko Itoga, Ms. Kaori Izumaru for their kind support.
We wish to express our appreciation to the participants. Requests for reprints should be addressed to the first author at Department of Psychology, University of the Sacred Heart, 4-3-1, Hiroo, Shibuya-ku, Tokyo 150-8938, JAPAN, e-mail : kawakami@u-sacred-heart.ac.jp

non-invasive method of evaluating fetal circulation, especially plancetal circulation (Nyberg, Mahony, & Pretorius, 1990). MAVW also evaluates fetal circulation, especially blood flow in the fetal brain. When the fetus is in severely status, UAVW resistance is increased and MAVW resistance is decreased. These circulation changes are related to fetal catecholamine (CA) levels (Sekizawa, Ishikawa, Sakama, Morimoto, Suzuki, Saito, & Yanaihara, 1995). CA elicts vasoconstrictive and cardiotonic actions. Fetuses stressed prenatally excrete cortisol and CA. When we can get good results by UAVW and MAVW resistances, we will be able to have new indices of human fetal auditory perception. The main purpose of this study is to evaluate UAVW and MAVW resistances as indices of human fetal responses to sounds.

Fetal auditory responses are thought to mature after about 30 weeks gestation (Kisilevsky, Muir, & Low, 1992 ; Kisilevsky, Pang, & Hains, 2000). But behavioral states are difficult to identify in fetuses less than 36 weeks GA (gestational age, cf. Kisilevsky & Low, 1998, p.12), so fetuses after 37 weeks GA were the participants in this study.

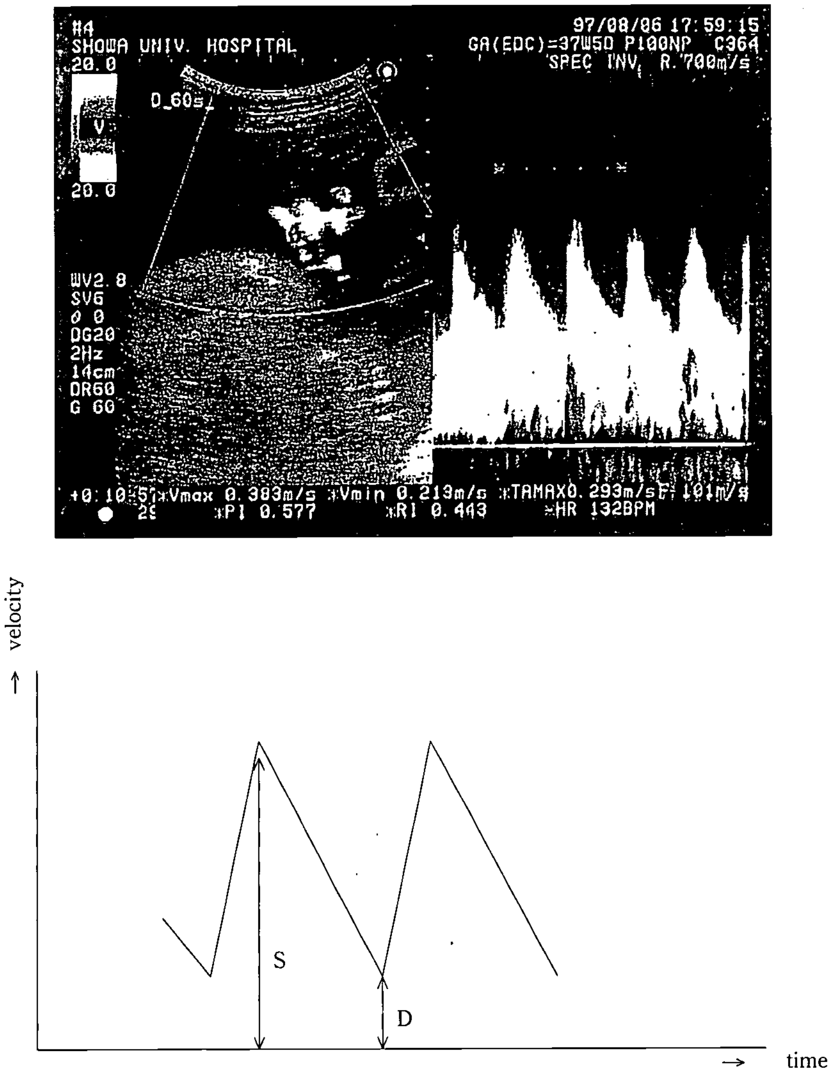
Effective sound stimulus intensity levels for fetuses have been studied, and 105 dB is regarded as the lowest threshold evoking a fetal response (Kisilevsky, Muir, & Low, 1989 ; Lecanuet, Granier-Deferre, & Busnel, 1988 ; Yao, Jakobsson, Nyman, Rabaeus, Till, & Westgren, 1990). Using a hydrophone, Richards, Frentzen, Grehardt, McCann & Abrams (1992) showed that when sounds generated outside the mother pass into the uterine environment, the dB of their constituent frequencies are differentially enhanced/attenuated. But even now 105dB is regarded as the critical threshold (Kisilevsky et al., 2000), so 105dB is used as stimuli in this study.

In our previous studies, we have shown the calming effect of sound on newborns experiencing stress induced by heelstick (Kawakami, Takai-Kawakami, Kurihara, Shimizu, & Yanaihara, 1996 ; Kurihara, Chiba, Shimizu, Yanaihara, Takeda, Kawakami, & Takai-Kawakami, 1996). The presentation of white noise (NOISE) had the strongest calming effect (Kawakami et al., 1996) and the presentation of the sounds of Japanese drums (DRUM) had only a minor effect (Kurihara et al., 1996). We presented the attention hypothesis: NOISE might shift attention of newborns from pain to hearing. The second purpose of this study is to evaluate fetal attentional responses to sounds by analyses of UAVW and MAVW resistances.

Method

1. *Participants*

Nine healthy volunteer women, between 37 and 39 weeks gestation, participated in the study. However, data for one woman at the MAVW session could not be obtained because major fetal movement precluded measurement. All her data were eliminated from the analysis. We obtained the informed, written consent of all participants. Information regarding socioeconomic status is not recorded in Japanese hospitals. The mean age of the mothers in this study (M = 30.88, SD = 5.74) matched that of pregnant women in Japan. All mothers had no difficulties in these pregnancies and no smoking habit. Although all experiments were performed at Showa University Hospital in Tokyo, the births eventually took place at several hospitals in Tokyo. All infants, 5 males and 3 females, were apparently healthy at the time of birth.



S : Systolic D : Diastolic

RI (resistance index) = (S − D) ／S

Figure 1 Results of UAVW for one case.

2. Stimuli and Equipment

NOISE was generated by sound-editing software running on an Apple Macintosh Computer. DRUM was obtained from a compact disk recorded by the Japanese drum group " Ondekoza ". The NOISE used in this study maintained a consistent sound pressure over the frequency range from 0 to 10000 Hz. There is a possibility that the results will be changed when we use NOISE from 0 to 20000 Hz. But we used NOISE from 0 to 10000 Hz in this study, because we used it to be consistent with our previous studies (Kawakami et al., 1996). However, the DRUM sounds showed large sound pressure only at low frequencies, with amplitudes falling almost to 0 dB at frequencies above 2000 Hz.

NOISE and DRUM were recorded on a mini-disk, and were played back on a Sony mini-disk deck (MS-M5). The mini-disk deck was programmed to play a series of sound stimuli of 5 seconds duration followed by a 1 minute pause. The peak sound pressure level in each stimulus, 105 dB using the C scale, was measured by a Rion sound pressure meter (NA-80) and a Rion condenser microphone (UC-30).

Fetal heart rate monitoring was performed with a Corometrics 145 (Atom Inc.). Doppler monitoring was used to obtain a fetal heart rate (FHR) and a rate of uterine contraction (Tucker, 1989).

UAVW and MAVW were obtained by an ultrasound pulse Doppler unit (LOGIQ500MD, GE·Yokokawa Medical Systems Inc.). Figure 1 shows a section of UAVW data with explanations of the indices.

3. Design

There were three sessions (fetal heart rate monitoring, UAVW, and MAVW) and two stimulus conditions (NOISE and DRUM). In each session participants were presented with both stimulus conditions. The design of this study was to find the effect of sound presentation, so we fixed the order of these sessions (fetal HR, UAVW, & MAVW). The order of sessions was fixed and the order of stimulus conditions was counterbalanced, yielding a confounding design requiring a minimum of 8 participants (Iwahara, 1965).

4. Procedure

The sessions lasted 1-2 hours depending on the state of the fetus. At the time of sound presentation, mothers, wearing earplugs and a headphone set (MDR-CD570, Sony), listened to CD music selected by themselves from several kinds of CDs (using a Sony CD deck, CFD-370).

First, the fetal heart rate monitoring session was performed. The mini-disk deck was held approximately 10 cm from the maternal abdomen. For example, 105 dB NOISE was presented three times separated by 1 minute pauses and 105 dB DRUM was presented in the same manner. The order of NOISE and DRUM was counterbalanced across participants. Second, the UAVW session was performed the same way as the fetal heart rate monitoring session. Finally, the MAVW session was performed. All the three sessions (the fetal heart rate monitoring session, the UAVW session, and the MAVW session) were started when the FHR was stable and no fetal movement were detected. It was difficult to get the data of the ultrasound pulse Doppler unit when the fetuses moved too big. So all the fetuses should be in the quiet state (state 1F; Nijhuis, 1995) when the sessions were started.

Results

1. Fetal heart rate monitoring session

Coding of means of basal HR (beat/minute) and presence/absence of HR acceleration was performed by two analyzers independently. HR acceleration was defined by two criteria: over 15 bpm from basal line and lasted more than 15 seconds. The percentage of intercoder agreement was 96.2. A one-way ANOVA with a repeated measures factor for means of basal HR (pre-stimulus, NOISE and DRUM) was performed. There was no significant main effect ($F(2, 14) = 0.01$). HR acceleration occured in 16.7% of NOISE conditions and 26.1% of DRUM conditions.

2. UAVW session

Ultrasound pulse Doppler waveforms were recorded on a videotape. Monitor frames were stopped every 10 seconds (see Figure 1), and the average of resistance index was calculated. These procedures were independently performed by two analyzers, and the percentage inter-analyzer agreement was 93.0. The resistance index average will be denoted by X.

Figure 2 shows the data for one subject. The x-axis shows the 10 seconds segments. In ultrasound pulse Doppler waveforms changes of resistance index are important. Then sequential differences of X were calculated. If we denote X at time t as Xt, then the next segment (10 seconds later) will be called X(t+1). Figure 3a shows the means of sequential differences ($\bar{d} = 1/(n-1) \sum_{t=2}^{n} |Xt - X(t-1)| \times 1000$)[1] of all subjects in the pre-stimulus, NOISE and DRUM conditions. A one-way ANOVA with a repeated measures factor for $\bar{d}$ (pre-stimulus, NOISE and DRUM) found that the main effect was significant ($F(2, 14) = 7.88$, $p < .01$); inspection of means of sequential differences indicates that DRUM had higher levels than pre-stimulus.

3. MAVW session

Figure 3b shows the means of sequential differences of all subjects in the pre-stimulus, NOISE and DRUM conditions. A one way ANOVA with a repeated measures factor for $\bar{d}$ (pre-stimulus, NOISE and DRUM) found no significant main effect, $F(2, 14) = 1.07$.

To compare the results of UAVW and MAVW sessions, a one way ANOVA with a repeated measures factor for d (UAVW and MAVW) was performed[2]. There was no significant effect ($F(1, 258)=1.45$).

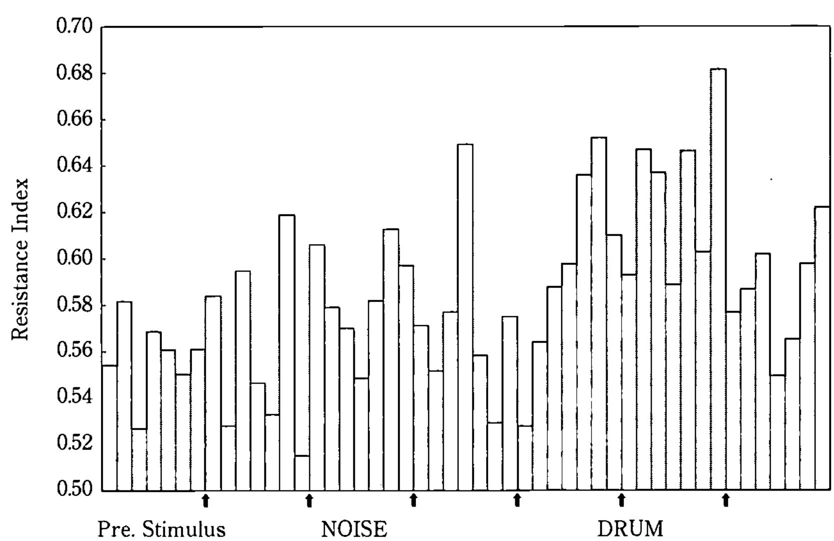


Figure 2 Changes of Resistance Index for one case.
Arrow means the stimulus presentation.

Discussion

Previous research has found that presentation of sounds elicites heart rate acceleration (Lecanuet et al., 1995), and that this trend becomes more clearly evident after 30 to 32 weeks gestation (Kisilevsky, 1995 ; Kisilevsky et al., 1992). Ambient intrauterine sound pressure levels ranged from 72 to 88 dB at 100 Hz, produced by maternal bowel sounds, blood flow, maternal vocalization and external noise (Richards et al., 1992 ; Smith, Satt, Phelan, & Paul, 1990 ; Benzaquen, Gagnon, Hunse, & Foreman , 1990). The intrauterine sound pressure levels ranged from 88.6 to 115.6 dB by 110 dB vibroacoustic stimulation (Eller, Scardo, Dillon, Klein, Atramm, & Newman, 1995), and about 85 dB by 90 dB human voice from 1.2m distance (Richards et al., 1992). From these reports on intrauterine sound, the sound levels which we presented were enough effective to fetuses as much as vibroacoustic stimulation. The small number of participants might cause the results of fetal HR monitoring session.

Cerebral and umbilical vascular resistance responses after vibroacoustic stimulation are significantly lower than those of pre-stimulation in normal fetuses. However, in growth restricted fetuses the responses to sound are different (Loy, Lin, Chien, Kim, & Chiang, 1997), so these responses are related with fetal condition. Our study is the first trial of fetal vascular resistance responses to airborne sounds : NOISE and DRUM. In the UAVW session there were significant differences before and after presentation of two sounds. But in the MAVW sessions there was no significant differences.There was no differences

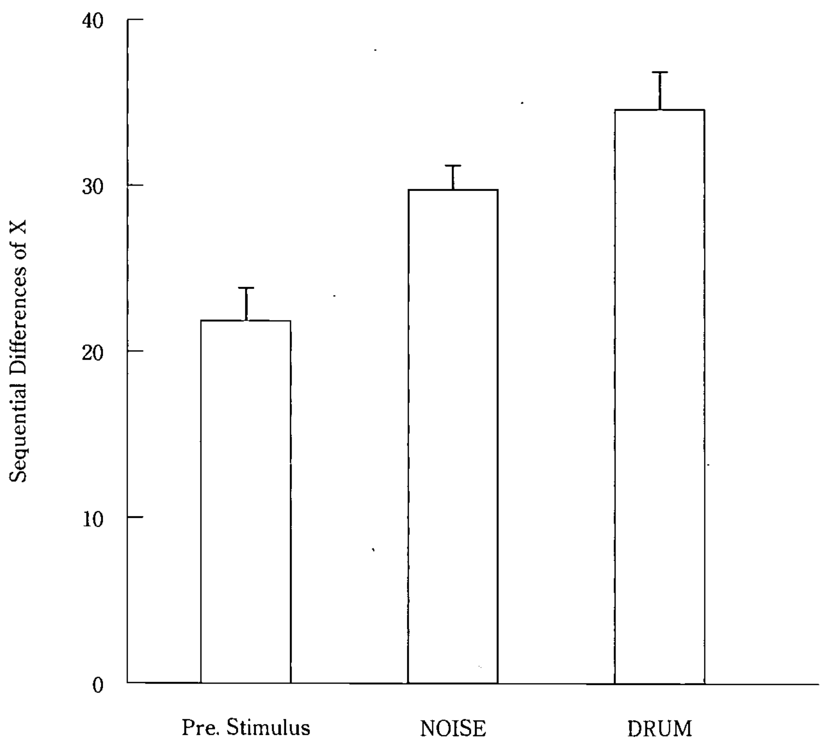


Figure 3a Means of sequential differences in UAVW.
Standard error of the means is indicated by the line above the bar.

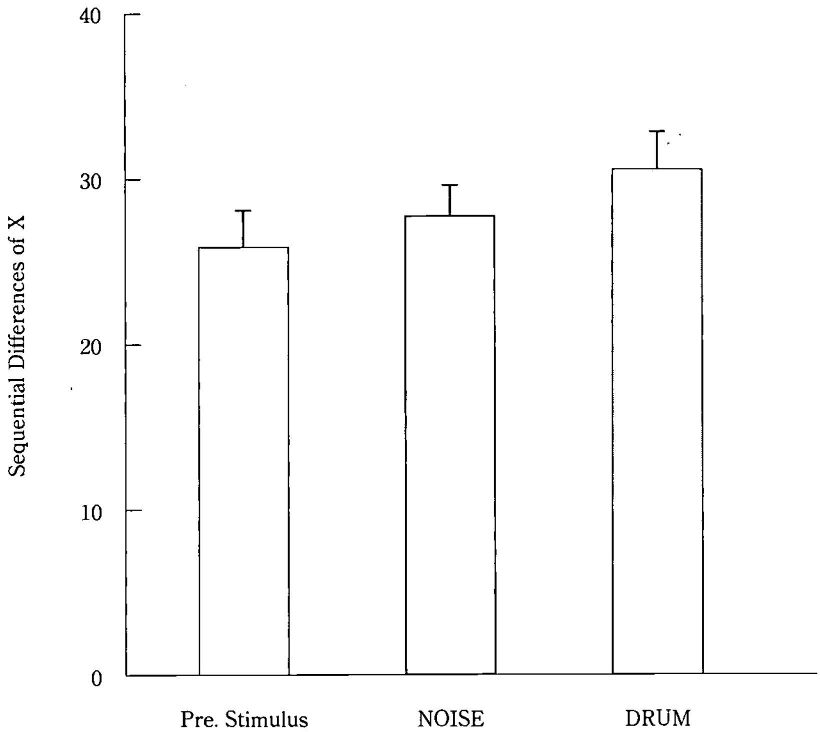


Figure 3b Means of sequential differences in MAVW.
Standard error of the means is indicated by the line above the bar.

in the data of UAVW and MAVW sessions, so we cannot explain these results by habituation. UAVW resistance may be very sensitive index of responses to sound even by small data. The main purpose of this study was to examine the possibility of UAVW and MAVW resistances as indices of responses to sound. We will be able to use UAVW resistance as the measure of resposes to sounds. For the reason of smaller changes in MAVW than UAVW, we might expect greater stability in central nervous system function.

Kisilevsky and Muir (1991) showed that, both before and after birth, noise and vibration elicited greater response than a simple tone. They used pinknoise, vibration and a harmonically simple tone. In our previous studies of newborns, NOISE was effective but DRUM was not (Kawakami et al., 1996 ; Kurihara et al., 1996), a result differing sharply from the outcome of the present study. This discontinuity may be explained by the much greater attenuation of higher frequency sounds as they pass into the intrauterine environment (Querleu et al., 1989 ; Richards et al, 1992). The low frequency sounds of DRUM (Kurihara et al., 1997) may have a greater effect on fetal responses for this reason. Other reasons may lie in the differences in design of the experiments. In our previous studies, stimulus presentation was continued until the end of the experiment, but in this study stimulus presentation was only 5 seconds. Also, in our previous studies, stimuli were presented during especially stressful situation. To more fully understand prenatal to postnatal changes in attentinal response to sound, it will be necessary to carry out further investigations using other experimental designs.

Notes

1 These values are too small, so multiplied by 1000.

2 The data of pre-stimulus were eliminated from the analysis.

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執筆者紹介（掲載順）

常田　美穂（北海道大学大学院教育学研究科博士課程）

陳　　省仁（教授・北海道大学大学院教育学研究科）

庭野　賀津子（東北大学大学院教育学研究科博士課程）

菅井　邦明（教授・東北大学大学院教育学研究科）

川上　清文（教授・聖心女子大学）

高井　清子（助教授・日本女子大学）

増田　直衛（教授・慶応義塾大学）

鈴木　　真（講師・昭和大学）

清水　幸子（講師・昭和大学）

矢内原　巧（名誉教授・昭和大学）

乳幼児発達臨床センター年報

第 24 号（2000－2001）

平成14年3月27日印刷　3月29日発行

編集者　陳　省　仁
　　　　室　橋　春　光
　　　　藤　野　友　紀

印刷所　興国印刷株式会社

発行者　北海道大学大学院教育学研究科
　　　　附属乳幼児発達臨床センター
　　　　〒060-0811 札幌市北区北11条西7丁目
　　　　☎（011）706-3106

ANNUAL REPORT
RESEARCH AND CLINICAL CENTER
FOR CHILD DEVELOPMENT
No. 24 (2000－2001)

Date of Printing: March 27, 2002
Date of Publication: March 29, 2002
Editors : Shing-Jen Chen,
Harumitsu Murohashi,
Yuki Fujino
Printer : Kokoku Printing Co., Sapporo
Publisher : Research and Clinical Center for Child Developmemt, Graduate School of Education, Hokkaido University
Nishi 7, Kita 11, Kita ku,
Sapporo 060-0811 Japan
Phone : 011-706-3106

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